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FLIGHT INVESTIGATION OF PERFORMANCE CHARACTERISTICS DURING LANDING APPROACH OF A LARGE POWERED-LIFT JET TRANSPORT

by Albert W. Hall, Kalman J. Grunwald, and Perry L. Deal

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SUMMARY

A flight investigation has been conducted to determine low-speed performance characteristics of an airplane employing a powered-lift system. The airplane used during this investigation was a modified jet transport which was equipped to provide engine compressor air for boundary-layer control over the wing trailing-edge flaps.

It was found that for powered-lift aircraft the approach speeds should be based on a given percentage of the power-on stall speeds, but not less than a fixed margin above the stall speeds. These criteria provided adequate maneuver capability for all configurations during instrument approaches. These approach speeds fell slightly below the speeds for maximum lift-drag ratio for all configurations, but this speed-thrust instability caused no objectionable characteristics. Problems encountered during this program which should be considered for operational powered-lift aircraft design were uncomfortable airplane approach attitudes and insufficient thrust margin at low approach speeds and maximum landing weights. Automatic speed control was found to be very effective in reducing pilot workload during instrument approaches.

INTRODUCTION

The development of the high-speed jet transport has emphasized the need for high lift to reduce the approach and landing speeds. Lower approach and landing speeds are desirable from the standpoint of reducing landing distance, lowering weather minimums, and obtaining greater safety. One method of increasing the lift coefficient of these airplanes is through the use of powered-lift systems such as the blowing flap (that is, blowing air over the surface of trailing-edge flaps).

The present civil certification requirements for performance (speed and maneuver margins) are related to a power-off stall speed. For powered-lift type of aircraft, where power is required to provide the high lift capability, the present criteria are no longer sufficient and new criteria need to be studied.

A flight investigation, in which a large jet transport is utilized, has been undertaken to obtain some data at low speed which will be useful in the determination of design and certification requirements for the landing approach of airplanes employing powered-lift systems. The results of this investigation relative to aircraft performance requirements such as speed margin and maneuver capability, speed stability, thrust margins, and attitude limits are presented in this paper along with some noise measurements showing the effect of utilizing this type of powered-lift system. Some preliminary results pertaining to both performance and handling qualities are presented in reference 1.

The airplane used in this study is considered to be a test bed rather than a final design for a typical powered-lift configuration; therefore, the performance limitations imposed by lift-drag characteristics, such as climb gradients and go-around capability, were not investigated. However, the effect of lift-drag characteristics on the low-speed performance requirements is an important factor to be considered and has been discussed in reference 2.

SYMBOLS

The units used for the physical quantities defined in this paper are given both in the U.S. Customary Units and in the International System of Units (SI) (ref. 3).

C_L — lift coefficient, $\frac{\text{Lift force}}{qS}$

$C_{L,a}$ — approach lift coefficient

$C_{L,max}$ — maximum lift coefficient

C_μ — blowing-momentum coefficient, $\frac{\text{Blowing momentum}}{qS} = \frac{\text{Mass flow} \times \text{Jet velocity}}{qS}$

D — airplane drag, pounds (newtons)

g — acceleration due to gravity

$\frac{dh}{dt}$ — rate of climb, feet/second (meters/second)

L — airplane lift, pounds (newtons)

n — load factor

q	dynamic pressure, $\frac{\rho V^2}{2}$, pounds/foot^2 $\left(\text{newtons/meter}^2\right)$
S	wing area, feet^2 $\left(\text{meters}^2\right)$
T	net thrust, pounds (newtons)
$\frac{dT/W}{dV}$	speed-thrust parameter, per knot
V	airspeed, knots
V_a	approach speed, knots
V_s	1g stall speed (power on), knots
V_{so}	stall speed (power off) as defined by Federal Aviation Regulations, knots
ΔV	speed margin, $V_a - V_s$
$\frac{dV}{dt}$	rate of change of speed, feet/second^2 $\left(\text{meters/second}^2\right)$
W	airplane gross weight, pounds (newtons)
γ	flight-path angle, radians
ρ	air density, slugs/foot^3 $\left(\text{kilograms/meter}^3\right)$

All airspeeds are equivalent airspeed except as noted in text.

EQUIPMENT

Descriptions of Airplane and Configurations

The airplane (refs. 1 and 2) used in the investigation was the prototype of the Boeing 707 (fig. 1) equipped to provide engine compressor air for boundary-layer control over the wing trailing-edge flaps for high lift at low speeds. In addition to the blowing flap system, the airplane wing was fitted with high lift devices on the leading edge and large trailing-edge flaps. The airplane weight varied between 130 000 pounds (578 000 newtons) and 180 000 pounds (800 000 newtons) during the tests.

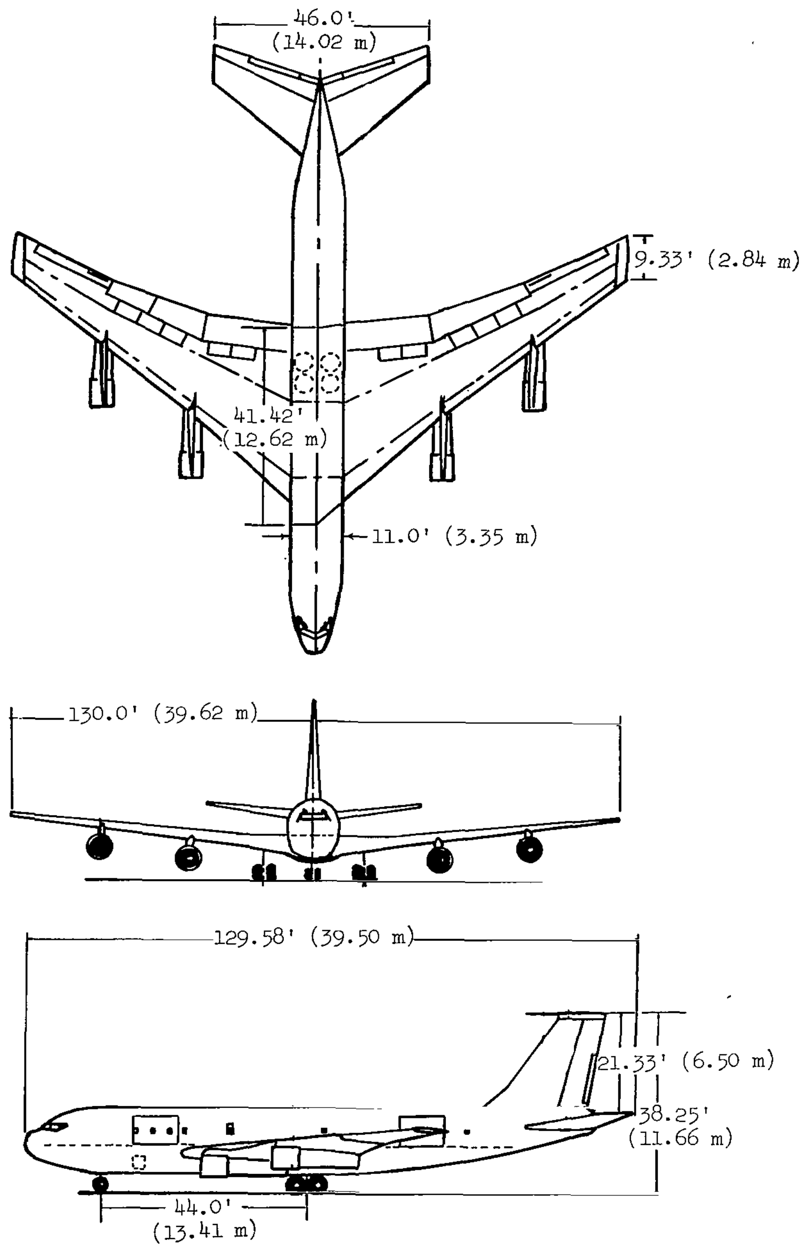

Figure 1.- Three-view drawing of test airplane.

A thrust modulation system was used in order to operate the engines at the high power required for the powered-lift system and still obtain the low (forward) thrust required for the landing-approach configuration. The clamshell-type thrust reversers located in each of the four engine tailpipes were modified to be continuously variable through their entire operation range from maximum thrust to essentially zero thrust by a set of four levers located on the pilot's console. For each powered-lift configuration the engine throttles were set to obtain the desired power and then remained fixed during the test maneuvers while the thrust modulators were used in place of the normal throttle control. During the landing approaches this thrust modulation system provided a fast-acting thrust response when compared with the thrust response normally obtained by throttle control.

By means of three different combinations of flap deflection and amount of air blown over the flap, three landing-approach configurations were investigated. Configuration I represented the basic airplane with no blowing and a 30° flap deflection. Configuration II had a 50° flap deflection with a blowing-momentum coefficient between 0.032 and 0.045. Configuration III had a 60° flap deflection with a blowing-momentum coefficient between 0.078 and 0.111. The momentum coefficient C_{μ} varied because the amount of blowing for each configuration was regulated by maintaining a constant ratio between the pressure of the blowing air in the ducts and the ambient pressure (the pressure ratios were 3 and 5.5 for configurations II and III, respectively). With a constant pressure ratio, C_{μ} varied inversely with free-stream dynamic pressure (airspeed).

Data Reduction

A comprehensive system of recording instruments was used for this investigation. Most of the data were recorded on magnetic tape which was processed by an automatic data reduction system. Some data, such as airplane weight, were determined from the flight engineer's records of fuel-gage readings. These data and other hand-recorded notes and events were correlated with the automatically recorded data by a common timer system which was continually displayed in the cockpit by a digital readout clearly visible from several locations.

The lift and drag coefficients were determined from data taken during steady level flight. The lift coefficient is based on the relation

$$C_L = \frac{Wn}{qS}$$

and, therefore, includes the vertical component of engine thrust and the horizontal-tail lift force required for trim. The drag coefficient is based on the drag determined from the relation

$$D = T - \frac{W}{g}\left(\frac{dV}{dt}\right) - W\gamma$$

where $\gamma = \frac{dh/dt}{V}$ (the velocities are based on true airspeed). The small deviations from steady level flight were found to be significant and had to be accounted for in the drag measurements.

The angle-of-attack data were obtained from measurements made by a fuselage mounted vane. This vane was calibrated for straight flight (no sideslip) by measurements of pitch attitude and flight-path angle.

Instrument Landing System

The glide slope (3° for this investigation) and localizer guidance for the instrument approach tests were furnished by a modified ground-based tracking radar unit. This equipment furnished ILS-type information to the airplane by means of the standard ILS data link (glide slope and localizer receivers).

TEST PROCEDURES

Three experimental test pilots were used to evaluate each of the three configurations. The piloting task was to determine the minimum instrument approach speed considered safe for each configuration.

Tests were first made at altitudes of 3000 to 9000 feet (914 to 2743 meters) to obtain rough indications of minimum approach speeds and to establish preliminary pilot opinion. The tests consisted of heading changes, simulated wave-off, flare or pull-up, and 5-knot speed changes from trimmed level flight by use of elevator only. These tests were made at three speeds which were approximately 1.2 times the 1g stall speed and 10 knots below and 20 knots above this speed. All tests were made under ideal weather conditions with very little turbulence.

Following the altitude evaluations, final pilot evaluation was made under simulated instrument approach conditions (evaluation pilot hooded). Each pilot made several approaches with each configuration and used the speeds selected during the altitude evaluation as a target value. The instrument approach task provided a precision pilot task to verify the previously chosen speeds and opinions as to the reasons for limiting the speeds to this value. By using these minimum safe approach speeds, the pilots were able to evaluate better the minimum or limiting conditions related to the performance criteria and to study handling qualities in the speed regime where problems would most likely occur. The significance of various factors which influence the selection of approach speeds has been discussed in reference 4 from a pilot's point of view.

RESULTS AND DISCUSSION

Aerodynamic Characteristics of Test Configurations

The maximum lift coefficients of 1.72 for configuration I and approximately 2.2 and 2.8 for configurations II and III, respectively, were based on flight measurements of the 1g stall speed (power on), that is, the lowest speed at which the lift and vertical component of thrust can equal the airplane weight.

The stall tests were conducted before the parameters (flap deflection, thrust reverser position, and blowing momentum) were selected to define configurations II and III. The variation of maximum lift coefficient with blowing-momentum coefficient given in figure 2 was interpolated between data which bracketed the desired configurations. The precision of the $C_{L,max}$ values for the powered-lift configurations is not known; however, it is believed that the variation shown in figure 2 is a reasonable representation of the two configurations. Because the $C_{L,max}$ values herein are intended to reflect concepts rather than absolute magnitudes, the precision of these values should not affect the following discussion and conclusions.

The $C_{L,max}$ values given in figure 2 result in a range of stall speeds from approximately 70 to 105 knots for the configurations and weight variations that were investigated (fig. 3).

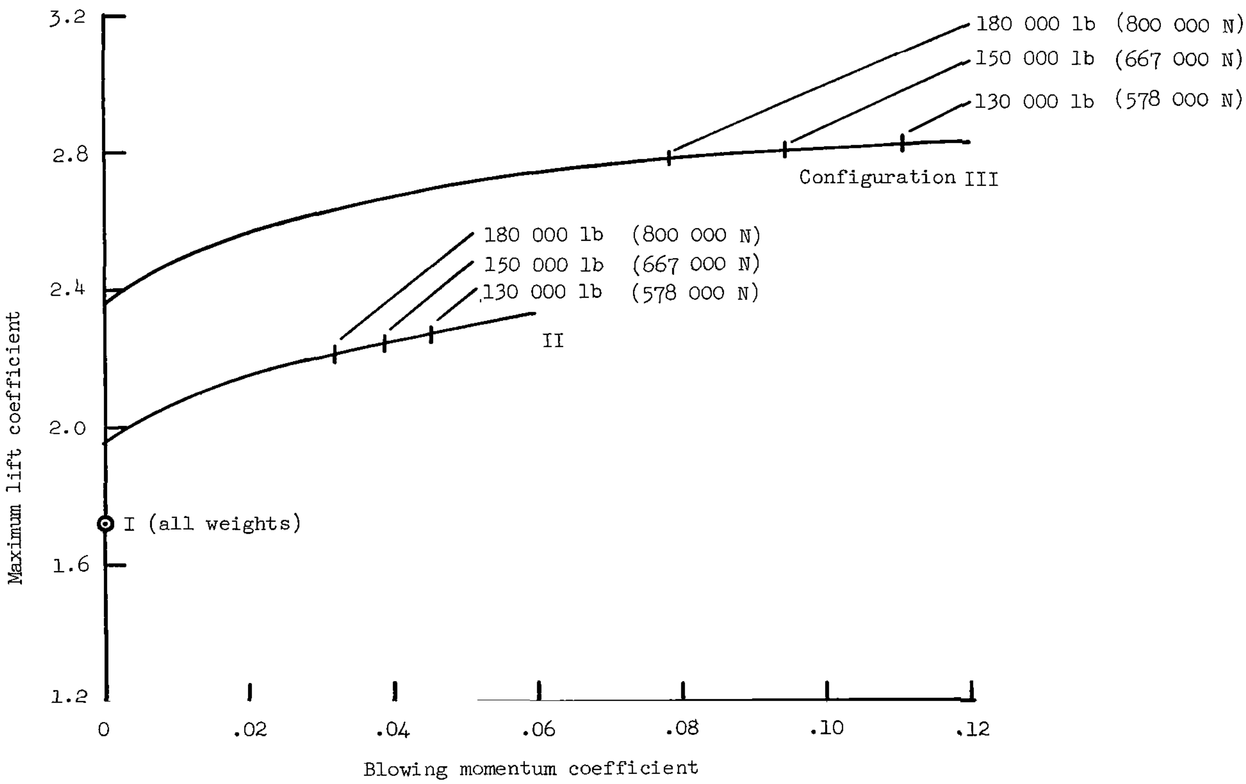

Figure 2.- Variation of $C_{L,max}$ with C_μ for the three test configurations.

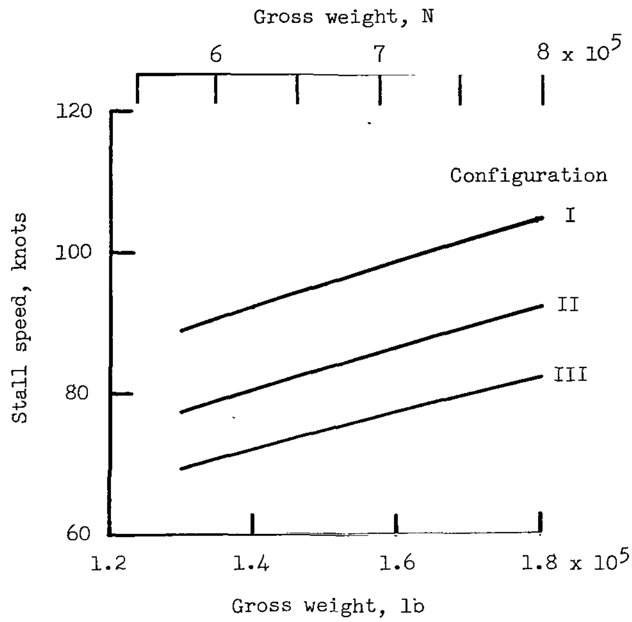

Figure 3.- Variation of 1g stall speed with gross weight.

The lift curves and drag polars given in figure 4 were obtained during the trimmed level flight at various speeds for the three configurations. An increase is noted in lift coefficient for a given angle of attack and also in the lift-curve slope for configurations II and III compared with those for the basic configuration. The drag polars show a substantial decrease in maximum lift-drag ratio for configurations II and III compared with the ratio for configuration I.

Operation of the powered-lift configurations at a fixed blowing-pressure ratio resulted in a variation of C_μ with airplane weight as indicated in figure 2. The change in C_μ is a result of the airspeed change associated with the weight change. The variation of $C_{L,max}$ was small for the range of C_μ and airplane weights used in this investigation.

Impingement Lift

For the large flap deflections used with the powered-lift configurations, the lift coefficient at a given angle of attack was approximately 20 percent higher without inboard-engine thrust reversal than with thrust reversal. Part of this increased lift is a result of the inboard-engine jet exhausting on the deflected flap and part is a result of changed airflow over the wing. To benefit from this increment in lift, it would be necessary to use full thrust on the inboard engines and control propulsive thrust by modulating the thrust of the outboard engine. For configuration II, however, too much propulsive thrust was available to allow modulation only on the outboard engines. Consequently, the thrust modulators were used symmetrically on all four engines. The steady-state aerodynamic characteristics given in figures 2, 3, and 4 represent configuration II with all thrust modulators deflected 30° (the nominal position for flying the 3° glide slope). For configuration III the excess thrust was so low that full advantage could be taken of the impingement lift. Consequently, this configuration was operated with thrust modulation on the outboard engines only. The aerodynamic data for configuration III are presented for full impingement from the inboard engines.

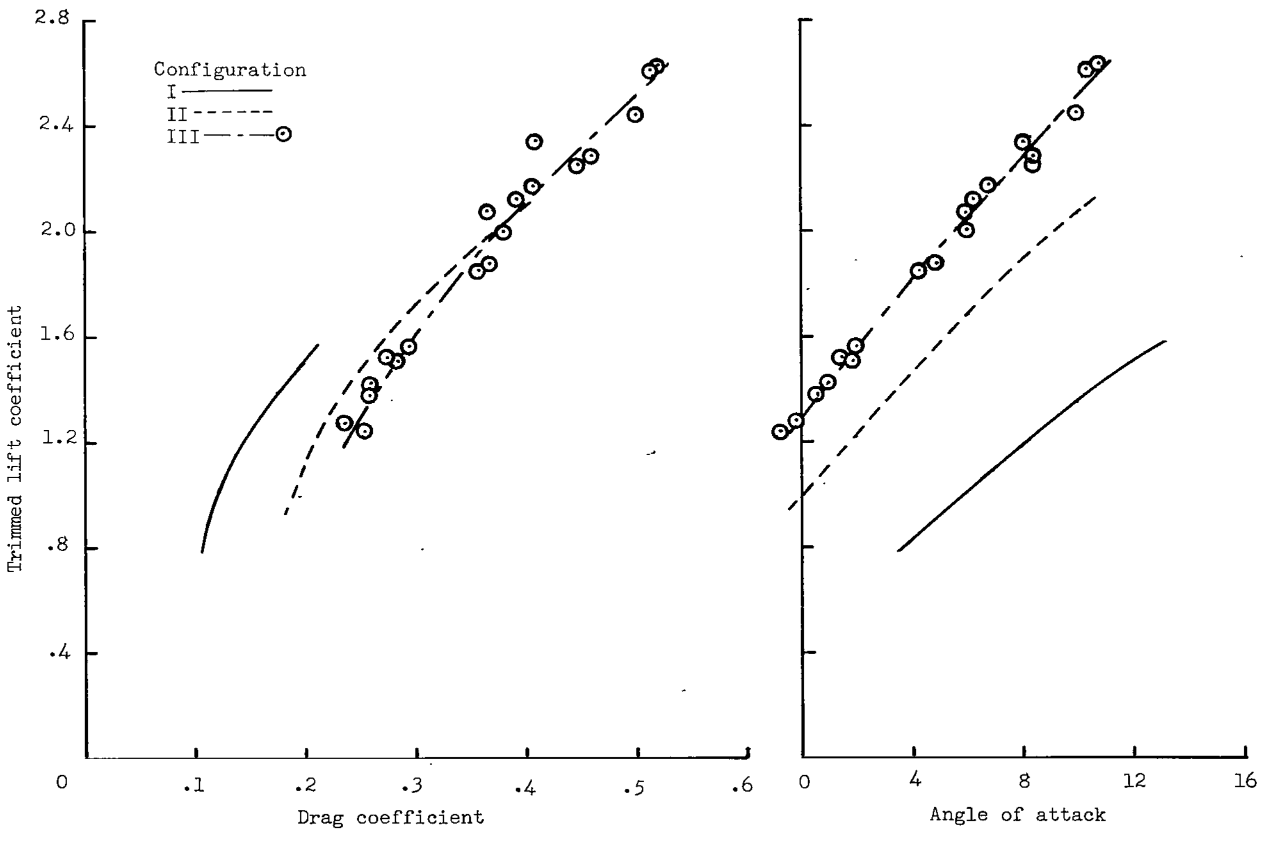

Figure 4.- Aerodynamic characteristics measured in flight. Data points are shown only for configuration III.

Minimum Approach Speeds

The curves in figure 5 represent the approach speeds determined by each pilot as a target value based on the evaluation of tests conducted at altitude. This variation of speed with weight is the result of a constant approach lift coefficient $C_{L,a}$, with the exception of the curve defined by pilot C for configuration III. For this configuration, the pilot wanted to decrease the $C_{L,a}$ for the higher weights in order to add a greater speed

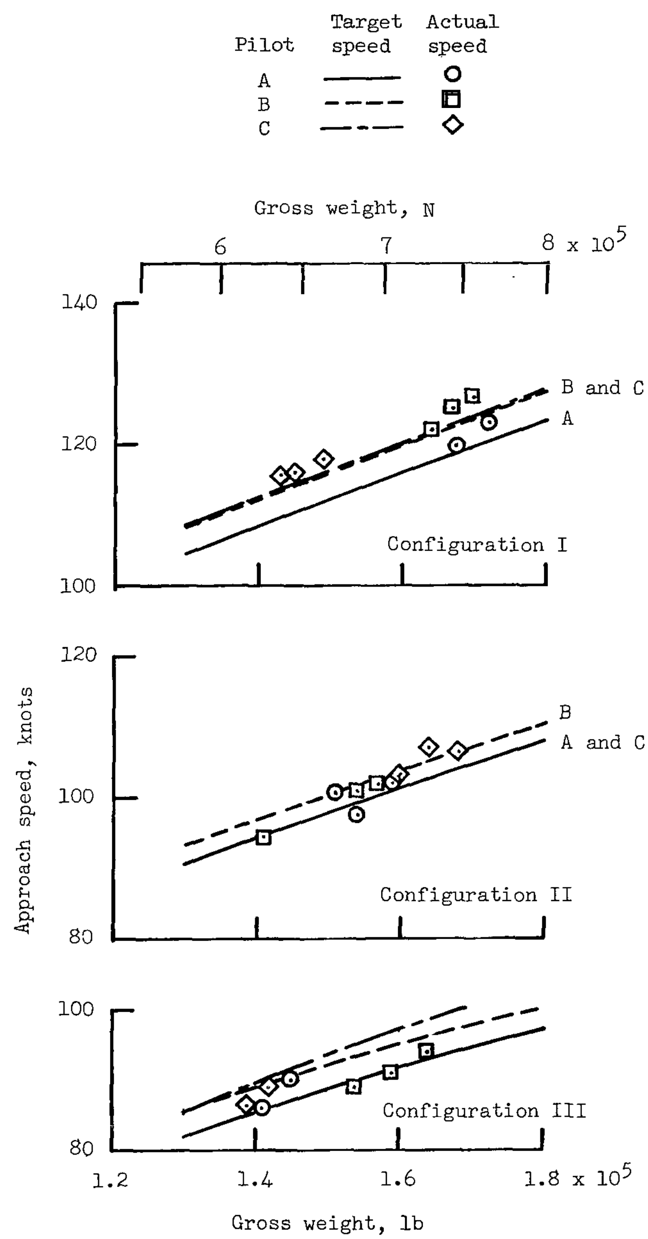

Figure 5.- Variation of approach speed with weight.

margin. Pilot C thought that a greater speed would be needed at higher weights to keep from inadvertently reducing the thrust margin to zero while operating on the back side of the thrust-required curve.

The symbols in figure 5 represent the average speed actually flown during each approach. The variation of speed during approach is illustrated in figure 6 by time histories of airspeed for portions of two approaches, one having relatively constant airspeed and one having considerable airspeed variation (manual speed control in both approaches). Generally, the variation of airspeed with time was between the two extremes illustrated in figure 6.

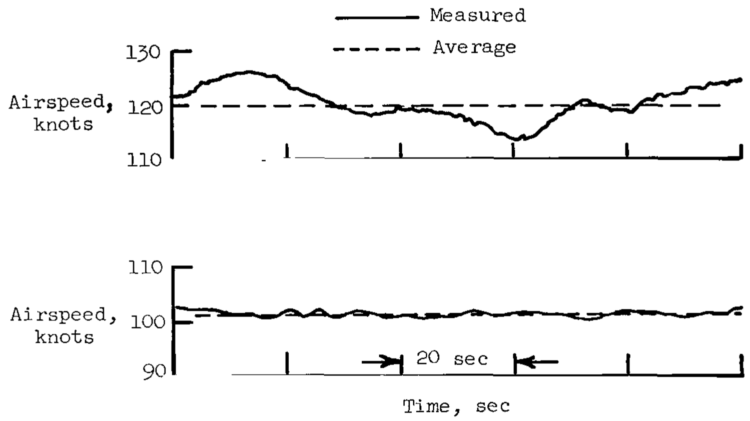

Figure 6.- Time histories of airspeed for portions of two approaches.

Speed Margin and Maneuver Capability

Speed margins and maneuver capability are necessary for the safe operation of airplanes. As a result, regulations have evolved through the years which establish minimum approach speeds that provide a safe margin above the stall speed which, in turn, assures a sufficient maneuver or "g" capability. Figure 7 illustrates the speed and maneuver margins currently applicable to commercial airplanes. The solid curve shows the variation with speed of C_L required for level flight for a wing loading representative of configuration I at a weight of 150 000 pounds (667 000 newtons). The dashed line represents $C_{L,max}$ for configuration I which is constant $\left(C_{L,max} = 1.72\right)$, over the speed range shown. Currently, by Federal Aviation Regulations (FAR) the minimum approach speed is 1.3 times the power-off stall speed, the stall speed being demonstrated by a specified procedure which allows the speed to be reduced at a rate not to exceed 1 knot per second. This procedure allows the airplane to slow to a speed below the 1g stall speed at a C_L near $C_{L,max}$ and about 0.8 or 0.9 of the C_L required for 1g flight (fig. 7). The FAR-type stall was not determined in this investigation but is represented by the cross-hatched area in figure 7 for the purpose of this discussion. The stall speed

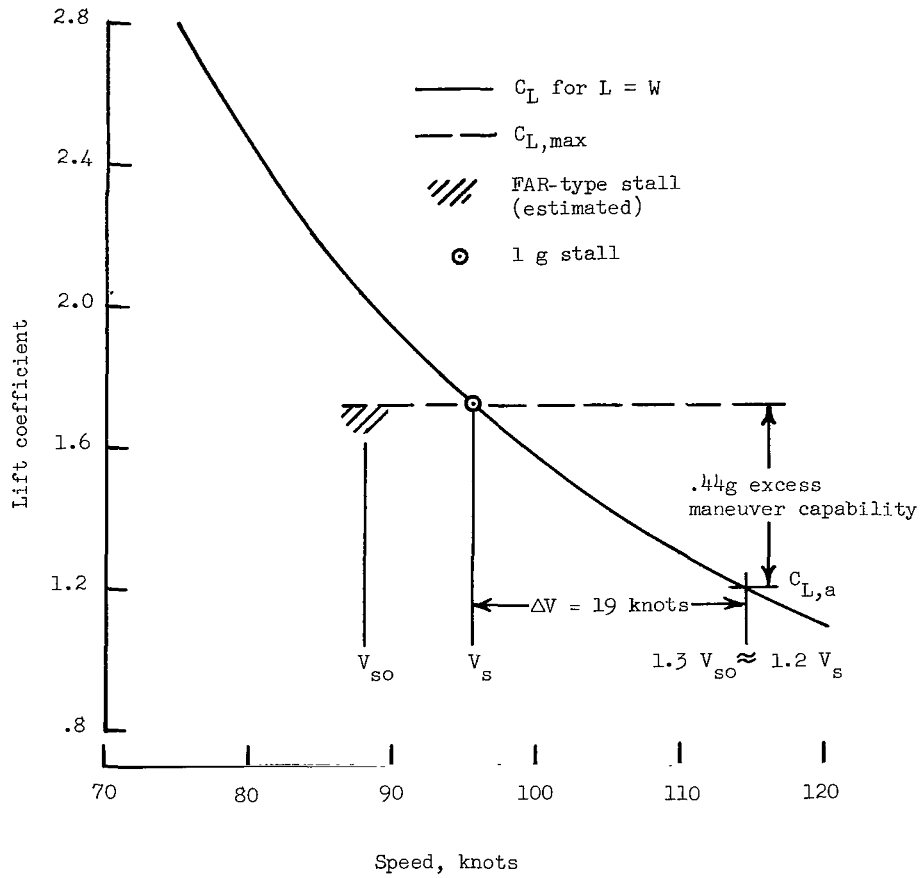

Figure 7.- Speed margin for configuration I at a weight of 150 000 lb (667 000 N).

used herein is the 1g power-on stall speed where lift equals weight and is shown in figure 7 as the intersection of the C_L required and $C_{L,max}$ curves. An approach speed of 1.2 times the 1g stall speed V_S is approximately equivalent to the minimum approach speed based on 1.3 times the FAR-type stall speed V_{SO}. This approach speed gives a maneuver capability of 1.44g – that is, $\frac{C_{L,max}}{C_{L,a}} = (1.2)^2$ (0.44g in excess of 1g condition, see fig. 7).

The variation of instrument approach speed with stall speed is shown in figure 8 for the three test configurations. The data show reasonable agreement with the straight line which represents an approach speed margin equal to 1.2 times the power-on 1g stall speed. For the range of stall speeds of the investigation, the minimum approach speed margins for these powered-lift configurations are similar to those presently used for conventional aircraft except that the reference speed would be the power-on stall speed instead of the power-off stall speed. That is, for the range of stall speeds of the

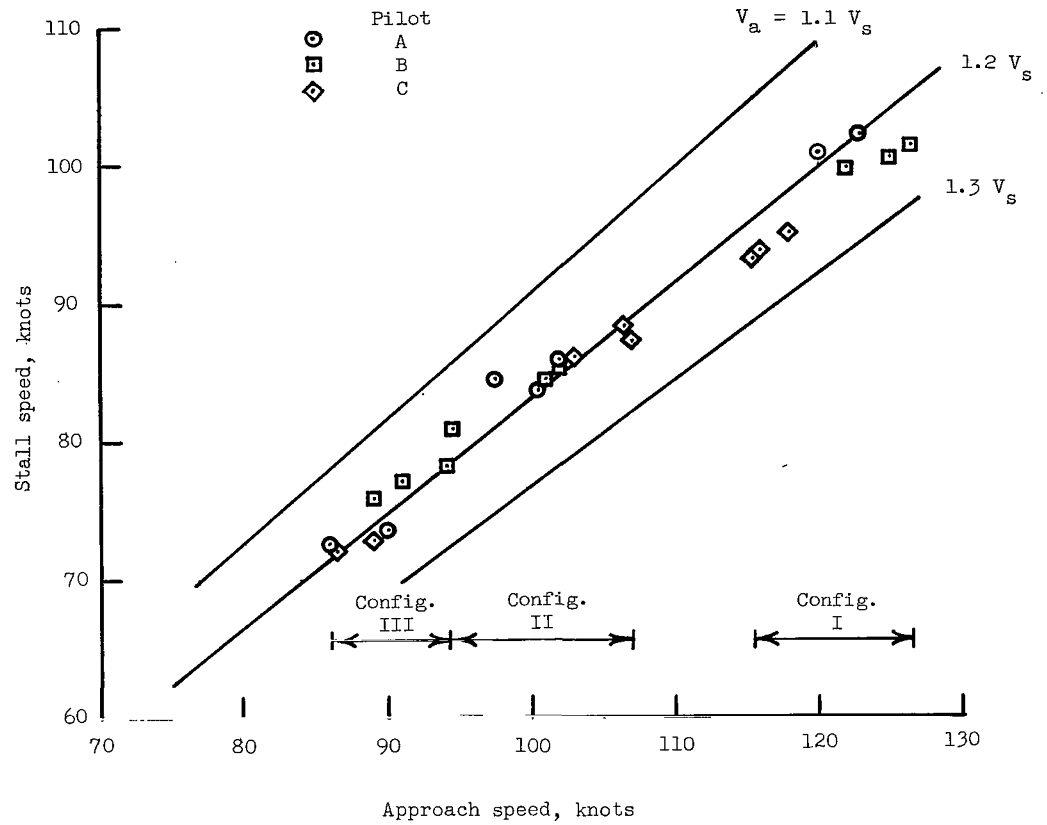

Figure 8.- Variation of approach speed with stall speed for instrument approaches.

investigation, the minimum approach speed could be expressed as $1.2V_S$ (without considering such effects as engine failure and thrust modulation on V_S which are discussed subsequently).

As the stall speed is decreased, the difference between the stall speed and an approach speed of $1.2V_S$ becomes so small (fig. 9) that the speed margin ΔV would not be sufficient to keep from inadvertently stalling the airplane during an approach. The pilots participating in this test program indicated that the minimum speed margin should be 10 to 15 knots. Even though the lower range could not be investigated, it is reasonable to assume that for low stall speeds the minimum approach speed would be governed by a requirement to provide a given speed margin.

Figure 9 illustrates a boundary for minimum approach speed which for all stall speeds will equal or exceed both a minimum speed margin and a given maneuver capability. For stall speeds below the intersection of the $1.2V_S$ curve and the $(V_S + \Delta V)$ curve, the speed margin is maintained and the maneuver capability is greater than that

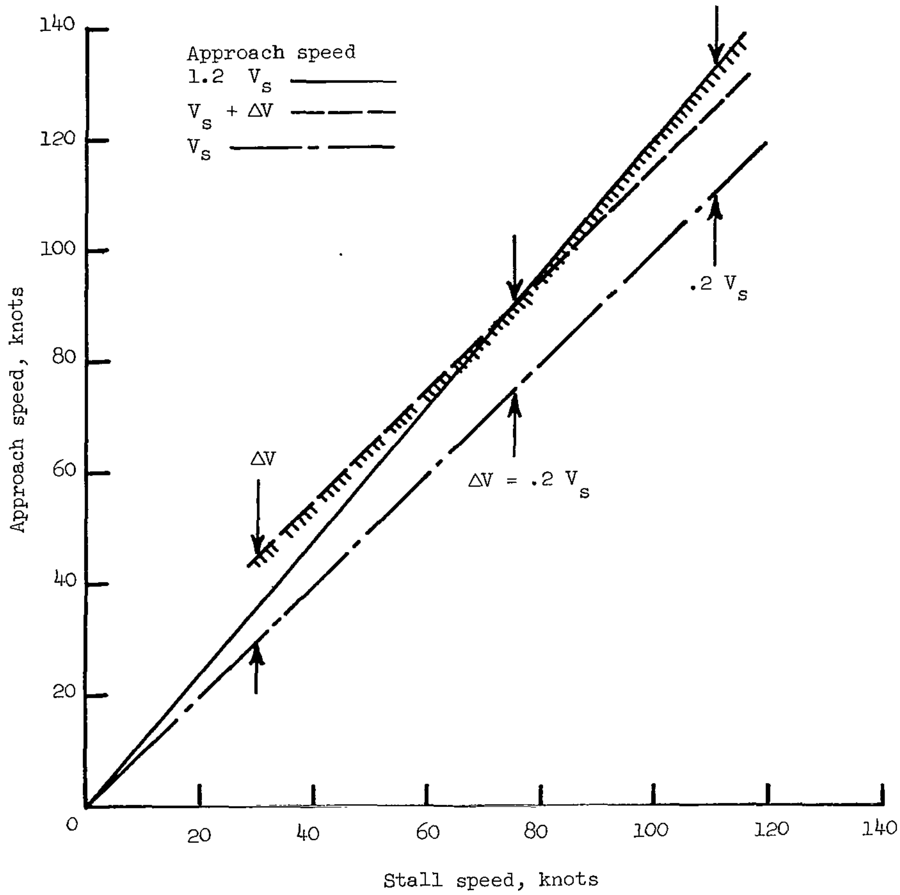

Figure 9.- Boundary for approach speed which is $1.2V_S$, or greater, and exceeds V_S by ΔV.

obtained at a speed of $1.2V_S$. For stall speeds beyond this intersection, the minimum speed margin is exceeded and the maneuver capability is based on the speed $1.2V_S$.

According to the pilots, the maneuver capability was adequate for all approach speeds investigated. The normal acceleration measured during instrument approaches and landing flares did not exceed 1.2g for all three configurations. The maneuver capability resulting from the $1.2V_S$ approach speeds varied from the 1.44g value for the conventional configuration (fig. 7) to values of 1.40g and 1.42g for the powered-lift configurations (fig. 10). The maneuver capability of the powered-lift airplanes is slightly less than that for the conventional airplane for the same speed margin ($1.2V_S$) because with powered lift the $C_{L,max}$ at the approach speed is less than $C_{L,max}$ at the stall speed (fig. 10). For the conventional configuration (fig. 7), $C_{L,max}$ at the approach speed is essentially the same as at the stall speed. If $C_{L,max}$ at the approach speed were significantly less than the value at the stall speed, the maneuver capability would be reduced to an inadequate level for what was previously acceptable as a speed margin.

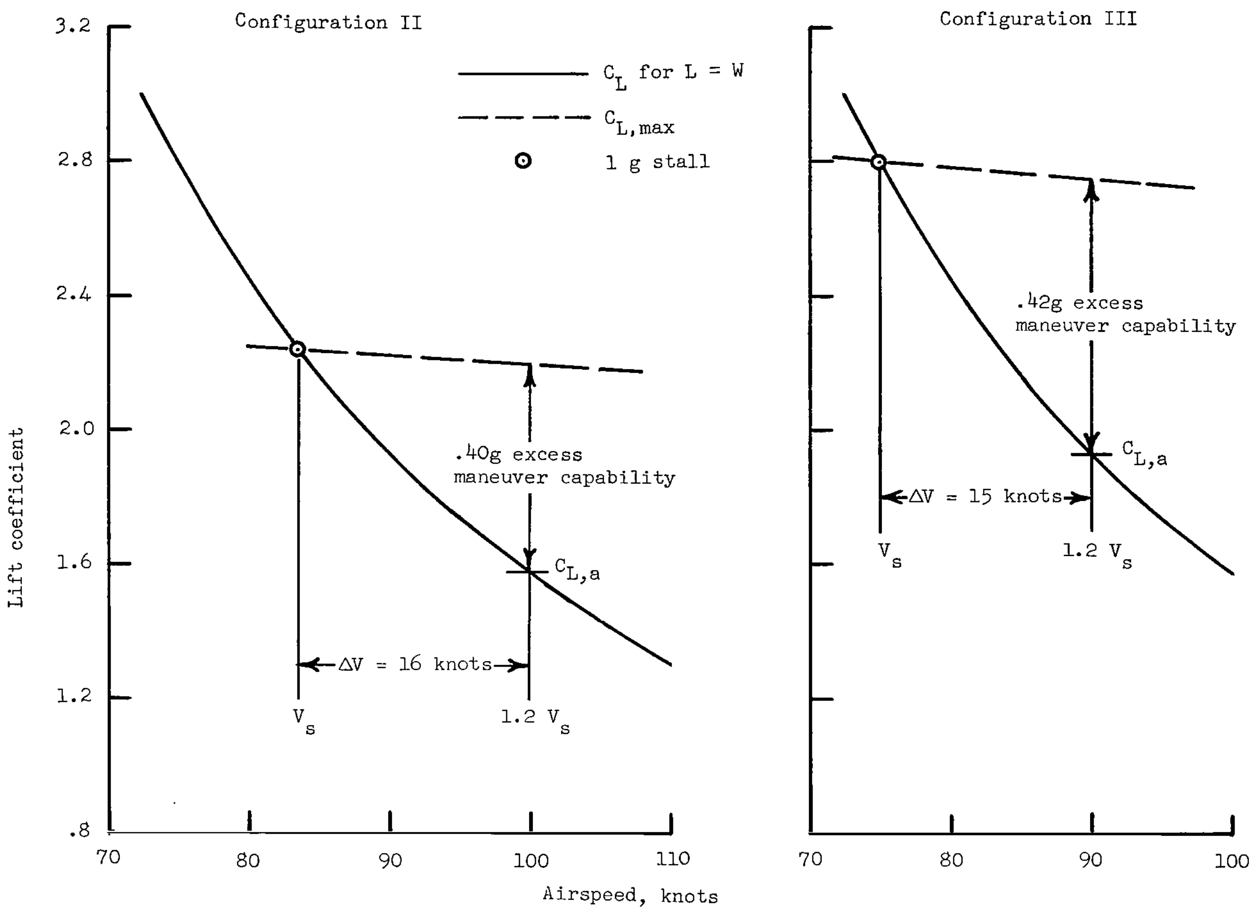

Figure 10.- Speed margins for powered-lift configurations at a weight of 150 000 lb (667 000 N).

In order to avoid a large decrease between the values of $C_{L,max}$ at the stall speed and at the approach speed, aircraft with powered-lift systems such as the type used for this investigation should be operated in the higher C_μ range where the variation of $C_{L,max}$ with C_μ has tended to be constant (fig. 2).

The aerodynamic data for configuration III includes thrust impingement lift from the inboard engines at full thrust. A loss of this impingement lift through an inboard-engine failure or through inadvertent use of inboard thrust modulators would decrease both the speed margin and maneuver capability as can be seen by lowering the $C_{L,max}$ curve in figure 10. If future powered-lift aircraft have a sizable variation in maximum lift capability because of variable methods of setting thrust, some criterion will be needed to determine the value of $C_{L,max}$ allowable in the determination of the power-on stall speed.

Speed-Thrust Stability

The approach speeds used by the pilots were either near the speed for minimum drag or on the back side of the thrust-required curve (fig. 11). The $1.2V_s$ speed was only 2 or 3 knots lower than the minimum drag speed (speed at $(L/D)_{max}$) for the higher speed configurations I and II, whereas $1.2V_s$ was 6 knots below the minimum drag speed for the lowest speed configuration III. Taking advantage of lower approach speeds by means of powered-lift systems is likely to result in flight on the back side of the thrust-required curve.

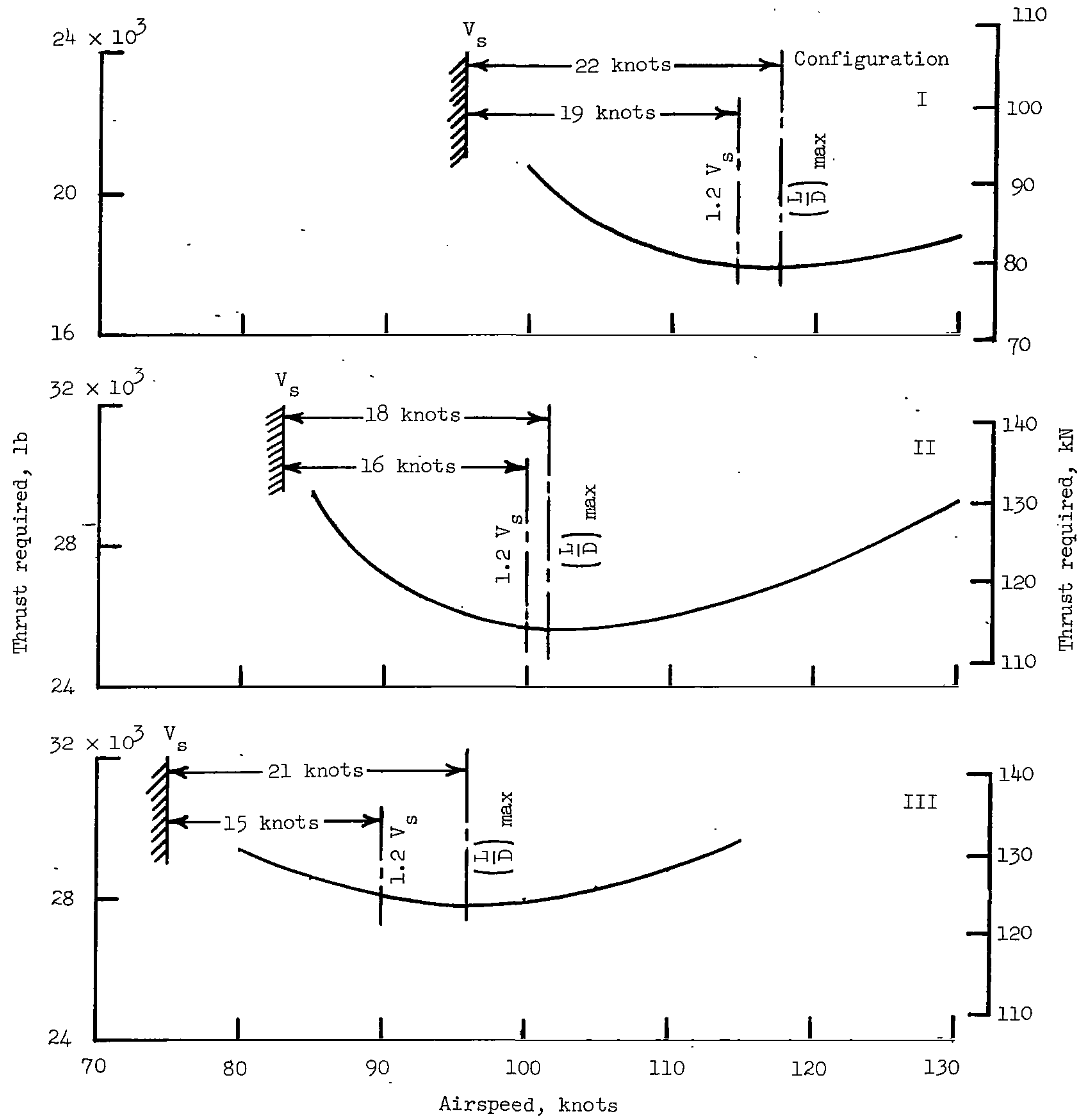

Figure 11.- Variation of thrust required for level flight with airspeed. (Sea level, standard day, 150 000-lb (667 000 N) gross weight.)

Although the pilots were aware of being on the back side of the thrust-required curve, they had no particular difficulty in making satisfactory instrument approaches. The effect of speed-thrust stability on the choice of instrument approach speeds has been discussed in several papers (for example, refs. 5 and 6). Reference 5 suggests that a certain amount of stability is desirable, whereas reference 6 indicates that negative stability can be tolerated until the value of the parameter $\frac{dT/W}{dV}$ exceeds -0.0012/knot. The present results, although not sufficiently detailed to be considered an investigation of the effects of speed-thrust stability, support the results of reference 6 in that a certain amount of negative stability can be tolerated. It should be noted here that the value of $\frac{dT/W}{dV}$ was -0.0006/knot at a speed of $1.2V_s$ for configuration III and was not considered a limiting value since the approach speed was limited by things other than speed-thrust stability.

Thrust Margin

The problem of providing sufficient thrust margin in the landing configuration at maximum landing weight must be considered in producing operational aircraft with powered-lift systems. For example, on a hot day configuration III of the present tests was thrust limited (had no climb capability) at high weights. At high weights, the increased thrust required combined with the decreased thrust available (a large amount of air was bled from the engines) resulted in insufficient thrust for level flight. This decrease in thrust available due to intermediate and maximum blowing can be seen in figure 12 along with the thrust required for level flight for configurations I, II, and III at a gross weight of 150 000 pounds (667 000 newtons). At 100 knots with no blowing (configuration I), the installed engine thrust is 51 700 pounds (230 000 newtons), whereas at this same speed the thrust drops to 37 900 and 28 300 pounds (169 000 and 126 000 newtons) because of the bleed air required for the powered-lift systems of configurations II and III, respectively.

During the test at altitude to determine minimum approach speeds for configuration III, one of the pilots thought that the low thrust placed a limit on the minimum speeds that could be used with configuration III. He stated, "The slope of the power-required curve on the back side appears to be such that you can control it [airspeed] without any problem if you had the thrust to do it with." This was the pilot who selected the higher target speed for approaches at higher weights (fig. 5). This speed addition (C_L reduction) was thought to be needed to keep from sliding so far up the back side of the thrust-required curve during a flare or large maneuver that the thrust required would exceed the thrust available.

Instrument approaches were flown (3° glide slope) with configuration III at weights as high as 167 000 pounds (743 000 newtons), and none of the three pilots reported any

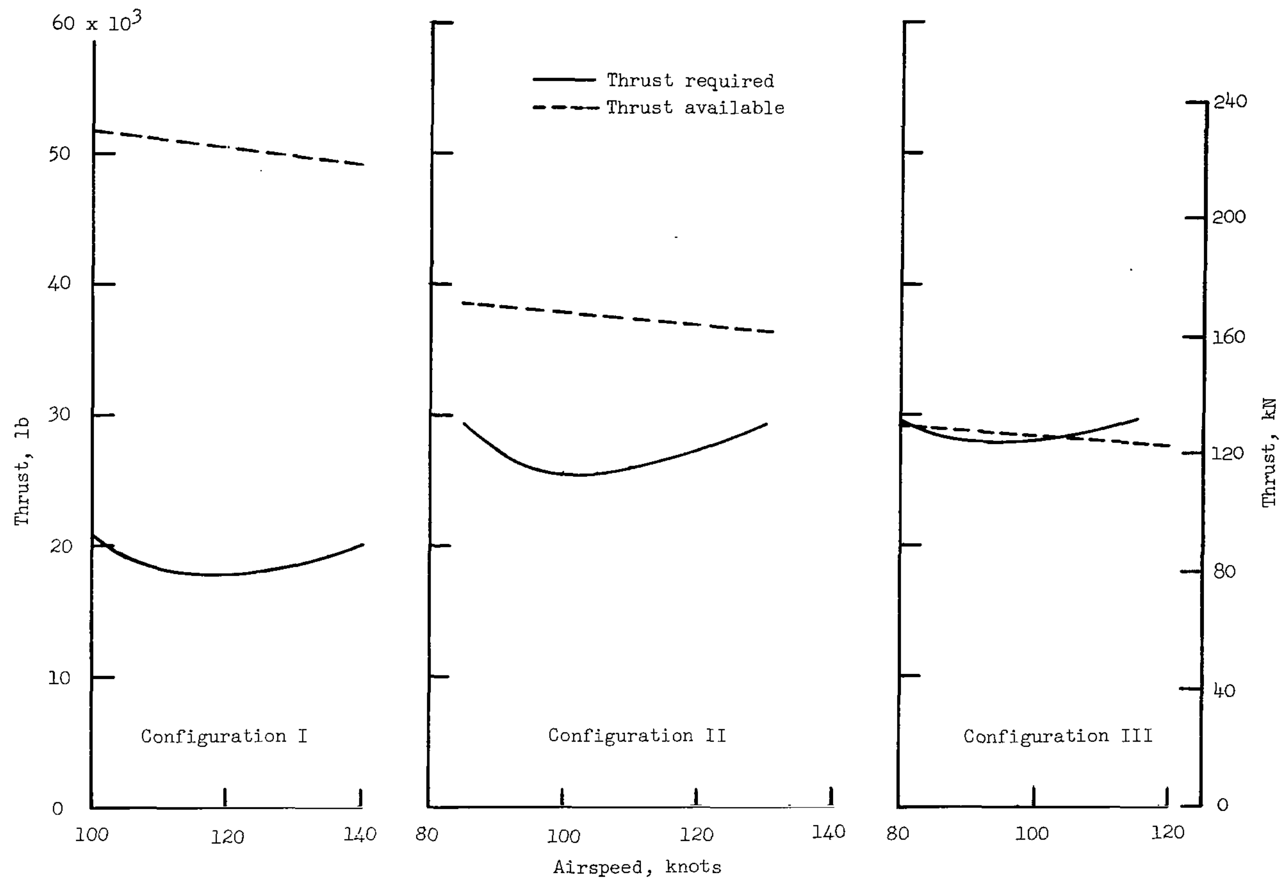

Figure 12.- Variation with airspeed of thrust available and thrust required for level flight. (Sea level, 90° day, 150 000-lb (667 000 N) gross weight.)

detrimental effects of low thrust. The thrust required for the 3° glide slope is approximately 8000 pounds (35 600 newtons) less than that shown in figure 12 for level flight.

The problem of thrust margin is one of design, and no special regulation would be required for powered-lift aircraft. The present one-engine-out climb requirements for transport category airplanes should insure adequate thrust for the landing-approach configuration.

Attitude Limitations

In choosing an approach speed, the pilots were very much concerned with airplane attitude. Apparently, when flying large transport-type aircraft, pilots prefer to make an approach with the airplane at or near the touchdown attitude so that little rotation of the airplane is required for the landing flare. Figure 13 shows typical attitude variations from the approach to touchdown for the conventional configuration I and the powered-lift configuration III. For each configuration, the attitude is increased about 2° during the landing flare.

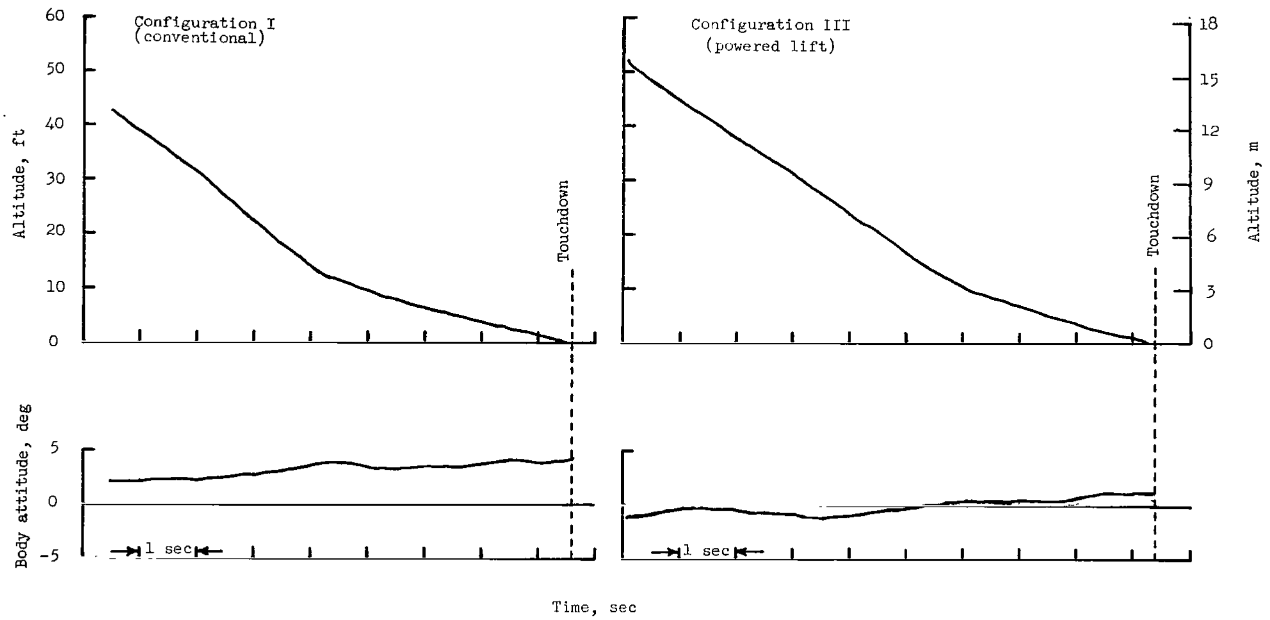

Figure 13.- Flare path and body attitude during landing for both conventional and powered-lift aircraft.

Figure 14 shows the angle of attack and lift coefficient for various approach speeds for each configuration. The body attitude for steady flight along a 3° glide slope is also shown on the bottom scale (wing angle of incidence $+2^{\circ}$). According to two of the three pilots, attitudes greater than those shown for configuration I would have been uncomfortably nose high and all pilots agreed that attitudes lower than those shown for configurations II and III would have been uncomfortably nose down. Thus, the nose-high attitude restriction tended to limit the minimum approach speeds for configuration I, and the nose-down attitude restriction limited the maximum approach speeds for the powered-lift configurations II and III. A design problem could develop for powered-lift aircraft if there is a large difference in the attitude for cruise and the attitudes for approach and touchdown.

Automatic Speed Control

The effectiveness of automatic speed control with powered-lift aircraft was investigated briefly during this flight program. Time histories of airspeed and thrust reverser position are given in figure 15 for two instrument approaches made by pilot C with configuration III. For all approaches with automatic speed control, the airspeed was held within 2 or 3 knots of the desired value; whereas, the deviation was much greater than this for some approaches with manual control (fig. 6). There were also many instances when the airspeed deviations with manual control were just as small as when flying with

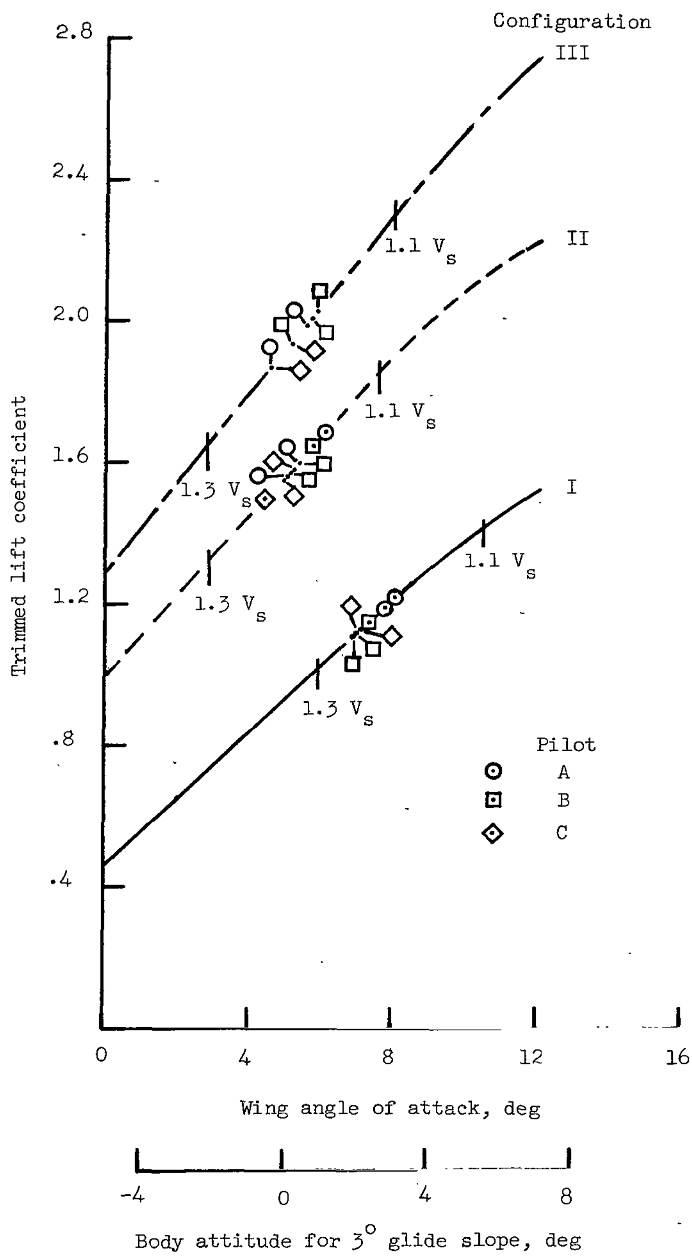

Figure 14.- Lift coefficient and angle of attack for various approach speeds.

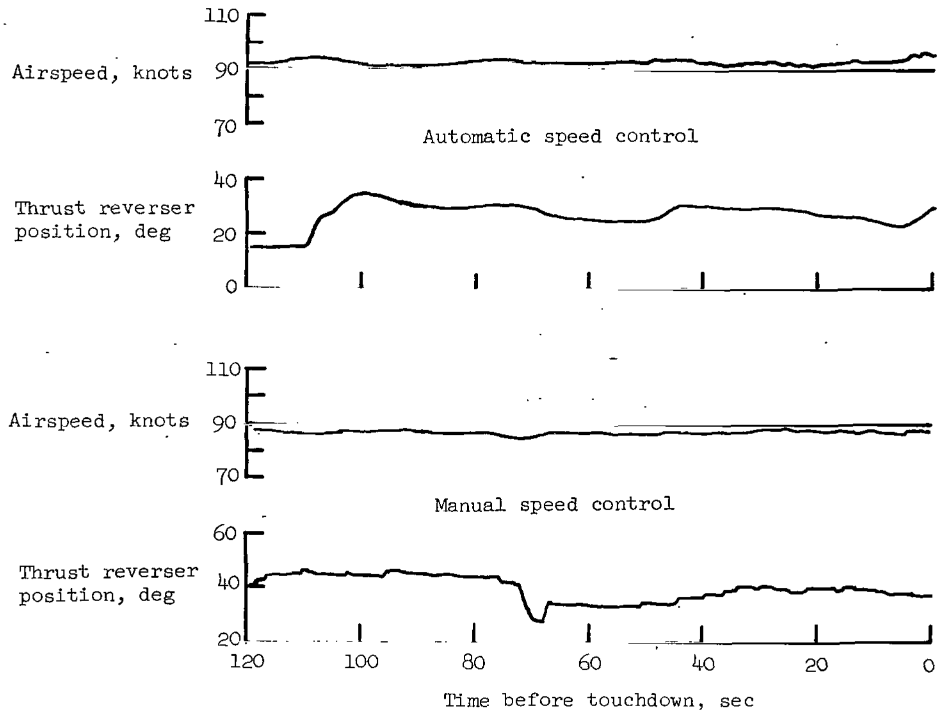

Figure 15.- Time histories of airspeed and thrust reverser position during two instrument approaches with configuration III.

automatic control. (See fig. 15.) The significant point is that in the manual-speed-control approach the pilot had to give considerable attention and effort to controlling the airspeed, whereas in the automatic-speed-control approach the pilot was completely relieved of this task. The pilot effort required for airspeed control is indicated to some extent by the time history of thrust reverser position in figure 15. Each movement here represents a control motion which required a certain amount of time, mental effort, and physical effort.

One-Engine-Out Capability

The present regulations relative to one-engine-out minimum control speeds and climb capability would seem to be adequate; however, compliance with the minimum control speeds could become a design problem or could limit the desired low approach speed. The problem could result from the application of full thrust on an outboard engine at a low approach speed where the available aerodynamic control force would be low.

In addition to the present one-engine-out requirements for minimum control speeds and climb capability, the one-engine-out capability of powered-lift aircraft must be considered from the standpoint of the effect of an engine failure on the maximum lift coefficient. For configuration III, considerable thrust impingement lift would be lost and an unsymmetrical spanwise distribution would result. If, however, there were no appreciable thrust impingement lift, the engine failure effect could be compensated for by proper design of the ducting which supplies the engine compressor air for boundary-layer control. The configuration used in this investigation utilized a dual system of nozzles, ducts, and manifolds so that the boundary-layer-control lift was reduced only about 4 percent by the loss of one engine.

Engine Noise

Engine noise is considered a problem with conventional jet aircraft during the landing approach. With this powered-lift airplane, the noise problem became more acute since high engine power was required during the landing approach for operation of the powered-lift system. Some noise reduction would be possible through increased blowing efficiency. The power levels required for this airplane are not necessarily representative of an optimized powered-lift configuration.

Some indications of the magnitude of this engine noise problem are shown in figure 16 wherein are presented the relative perceived noise levels (PNdB) for the basic

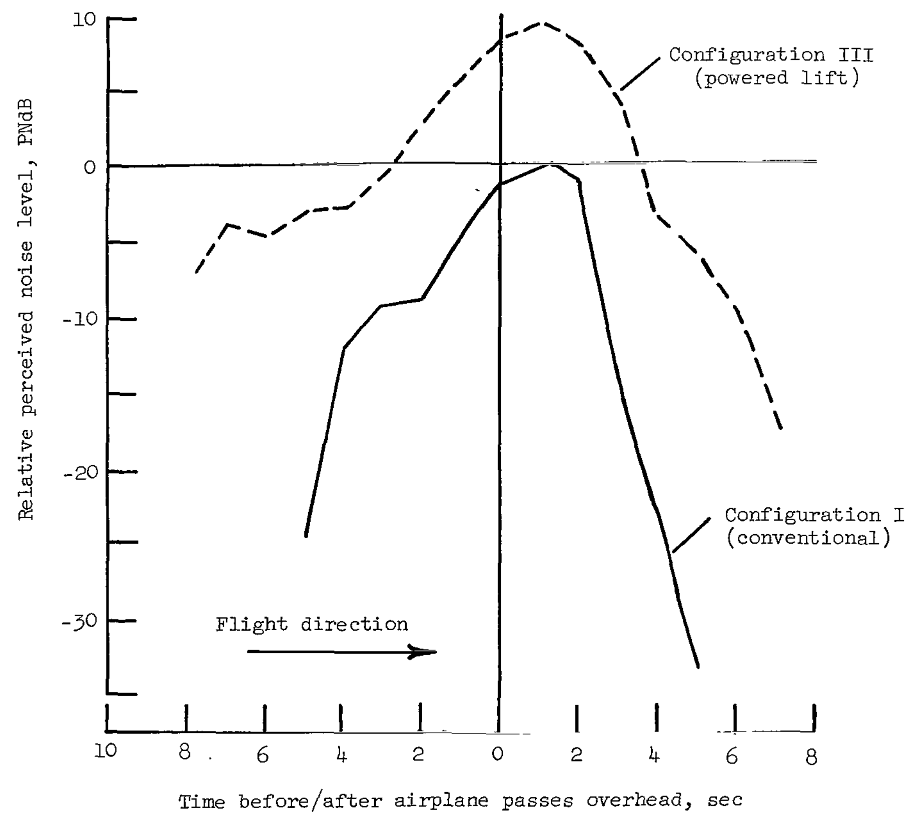

Figure 16.- Relative noise levels for airplane with and without powered lift measured at the ground under the approach path. (Ground station approximately 0.8 mile (1.29 km) from touchdown.)

airplane and the powered-lift airplane. From figure 16, it can be seen that the peak noise level for the powered-lift configuration was approximately 10 PNdB higher than that for the conventional configuration. Also, the duration of the higher intensity noise is much longer for the airplane with powered lift than for the conventional airplane. The results of reference 7 indicate that, if this increased duration was taken into consideration, PNdB ratings would be further increased. For example, doubling the duration of the same noise level would add approximately 4.5 PNdB to that noise level. The apparent increase in noise level with longer duration was quite noticeable to the people located below the powered-lift airplane during the landing approaches.

CONCLUDING REMARKS

A flight investigation has been conducted with a jet transport-type airplane employing blowing boundary-layer control on the flaps. Some of the low-speed performance characteristics which have been determined to be applicable to the landing approach design and certification requirements for future powered-lift aircraft are as follows:

Approach speed margins should be based on power-on stall speeds which account for loss of lift resulting from engine failure and particular methods of thrust control. The minimum approach speed should be a given percentage of the power-on stall speed but should not be less than a fixed margin above the stall speed.

Taking advantage of the low-speed capability of powered-lift configurations can result in approaches on the back side of the thrust-required curve. However, the pilots participating in this investigation did not object to operation slightly on the back side of the thrust-required curve during instrument approaches. Automatic speed control was found to be very effective in reducing the pilot workload during an instrument approach.

The powered-lift configurations showed sizable increases in noise levels which were primarily the result of higher engine power settings in the approach.

Problems encountered during this program that should be considered for operational powered-lift airplane design were uncomfortable aircraft approach attitudes and insufficient thrust margin at low approach speeds and maximum landing weights.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., July 13, 1967,
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